PHY 1010 – Introductory Physics
By Dr. S Mudenda

Units and Vectors

- Physics is the most basic/ fundamental of all the sciences. It is a quantitative and an exact science (meaning everything has to be expressed in terms of numbers).
- The goal therefore is to express these laws into mathematical forms.
- Since mathematics is the language of physics, we should find a way of quantifying physical quantities. One simplest way of quantifying is to count.
- This method is applicable wherever we have individual units such as apples, oranges, people, or atoms.

5

Units and Vectors

- Another method of quantifying is measuring.
- Unlike counting, though, the process is inexact. When measuring we no longer use integers to determine quantity.

6

Units and Vectors

- The raw material of physics is measurement.
- Every measurement is a comparison.
- When we say a boat is 18m long, it simply means the boat is 18 times a certain length called a metre.

$1m \times 18 = 18m$: $3kg$: $3 \times 1kg$.

- All quantities ~~have~~ in physics have thus a unit which has been agreed on internationally. These are called SI umts.

Units and Vectors

- There are seven fundamental quantities that are used to define/derive quantitites.
- These quantities are called basic quantities or basic units. (base units)

TABLE 1–5 SI Base Quantities and Units

	Quantity	Unit	Unit Abbreviation
1	Length	meter	m ✓
2	Time	second	s ✓
3	Mass	kilogram	kg ✓
4	Electric current	ampere	A ✓
5	Temperature	kelvin	K ✓
6	Amount of substance	mole	mol
7	Luminous intensity	candela	cd ✓

°C

Mole of a Substance

1 mol = N_a = 6.02×10^{23} objects (particles)

A mole of PHY 1015 Students

1 mole PHY 1015 contains 6.02×10^{23} students

Derived Units

All measures can be in terms of the basic or derived units.

- Derived units are from the base units

EX: Speed = $\frac{\text{distance}}{\text{time}}$

$$= \frac{[m]}{[s]} = m/s = ms^{-1}$$

$$a = \frac{v-u}{t} = \frac{[m/s]}{s} = m/s^2$$

$$a = m/s^2$$

$$F = ma$$

$$= [kg] \cdot [m/s^2] = kg\,m/s^2 = kg\,m\,s^{-2}$$

$$F = kg\,m/s^2 = \text{Newtons} = N$$

$$\underline{N \equiv kg\,m/s^2}$$

$$\text{Work} = F \times d \equiv \text{Joules}$$

$$= kg\,m/s^2 \cdot m$$

$$= kg\,m^2/s^2 = \text{Joules} = (J)$$

11

Prefixes

- Sometimes when making measurements/calculations, the magnitude of the numbers can be very large or very small.
- It is important use multiples of ten or prefixes.

 $\equiv 0.000001\,m = 1 \times 10^{-6}\,m$

$= 1\,\mu m$

12

Some magnitudes you may need to appreciate

TABLE 1–3 Some Masses

Object	Kilograms (approximate)
Electron	10^{-30} kg
Proton, neutron	10^{-27} kg
DNA molecule	10^{-17} kg
Bacterium	10^{-15} kg
Mosquito	10^{-5} kg
Plum	10^{-1} kg
Human	10^{2} kg
Ship	10^{8} kg
Earth	6×10^{24} kg
Sun	2×10^{30} kg
Galaxy	10^{41} kg

13

Prefixes

$mL = 10^{-3} L = \frac{L}{10^3} = \frac{L}{1000}$

TABLE 1–3 Some Masses

Object	Kilograms (approximate)
Electron	10^{-30} kg
Proton, neutron	10^{-27} kg
DNA molecule	10^{-17} kg
Bacterium	10^{-15} kg
Mosquito	10^{-5} kg
Plum	10^{-1} kg
Human	10^{2} kg
Ship	10^{8} kg
Earth	6×10^{24} kg
Sun	2×10^{30} kg
Galaxy	10^{41} kg

$10 \times 10^{-18} = 10^{-17} =$

$10\,a$

$1\,MB$

$= 10^6\,B$

$= 1000\,000\,B$

$1\,GB$

$= 1000\,000\,000$

$= 10^9$

$15f = 15 \times 10^{-15}$

$1\,cm \rightarrow m$

$1(10^{-2})\,m$

$10^{-2}\,m = 0.01\,m$

TABLE 1–4 Metric (SI) Prefixes

Prefix	Abbreviation	Value
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro†	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

† μ is the Greek letter "mu."

cm

↓

[illegible]

14

S. Mudende

Unit Conversion

- Direct Conversion
- Chain link Conversion

Direct:

$1 (mm)^2$ to m^2

$1 (10^{-3} m)^2 = 1 \times 10^{-6} m^2$

$1 mm^2 = 10^{-6} m^2$

Convert $km/hr \rightarrow m/s$

$\hookrightarrow \frac{10^3 m}{3600 s} = \frac{10^3 m}{3600 s}$

$1 \, km/hr = \frac{1000}{3600 s}$

$2 \, km/hr \Rightarrow \, m/min \Rightarrow \frac{2 \times 10^3 m}{60 \, min}$

$= \frac{2000}{60} m/min$

S. Mudenda

3 Cm into m

$3\ cm = 3 \times 10^{-2}\ m$

$3\ cm = 3 \times 10^{-2} = \underline{0.03\ m}$

4 kg into mg

$4(10^3)\ g = \underline{4000}\ g \Rightarrow mg$

$1\ mg = 10^{-3}\ g$

$x = 4000\ g$

$x = \dfrac{4000}{10^{-3}} = 4000000\ mg$

Chain link Conversion

The chain-link method of unit conversion prevents mistakes by keeping track of all the values, units, and conversion factors.

$y \times 1 = y$; $\dfrac{1000\ g}{1\ kg} = 1$ $\quad 1\ kg = 1000\ g$

To apply the chain-link method:

1. Write down the original value and units.
2. Set this equal to itself, only now with units written as a fraction.
3. Multiply by conversion factors to cancel undesired units and leave only desired final units.
4. Invert some conversion factors to get the undesired units to cancel, if needed.
5. Multiply the numbers across the top.
6. Multiply the numbers across the bottom.
7. Divide the top result by the bottom result.
8. Record the final value.
9. Add on the desired final units (top and bottom) that are left over after cancelling.

$3\ kg \rightarrow g$

$3\ kg = 3\ \cancel{kg} \times \dfrac{1000\ g}{1\ \cancel{kg}} = \underline{3000\ g}$

$3\ kg = 3 \times 10^3\ g = 3000\ g.$

S. Mudende

1 ft = 0.3048m

Convert 100 ft into metres.

$$100\ ft = \underbrace{100\ ft}_{} \times (1) = 100\ \cancel{ft} \times \overbrace{\left(\frac{0.3048\ m}{1\ \cancel{ft}}\right)}^{1} = 30\ m$$

Convert 24 m/s → km/hr

$$24\ \text{m/s} = 24\ \frac{\cancel{m}}{\cancel{s}} \times \overbrace{\left(\frac{1\ km}{10^3\ \cancel{m}}\right)}^{1} \times \left(\frac{3600\ \cancel{s}}{1\ h}\right) = \frac{24\times3600}{10^3}\ \frac{km}{h} \approx 86\ km/h$$

3600 s → 1 h : $\frac{1h}{3600s}$ or $\frac{3600s}{1\ hr}$

 1 $\qquad$ 1

S. Mudenda

~~BPM~~ BPM = heart beats per min

$y = x^{10}/10$

Everyday Example: Heart rate

Carlotta wants to determine her heart rate in **BPM.** She counts nine pulses is in six seconds. She then uses a conversion factor of ten to convert from beats per six seconds to **BPM** and determines her heart rate to be 90 **BPM**:

Beats / min

$$\frac{9b \times 10}{6s \times 10\ (60s)} = 90b$$

$$\frac{90b}{60s}$$

$$9\,beats\ per\ six\ seconds = \frac{9\,beats}{6\,\cancel{seconds}}\left(\frac{60\,\cancel{seconds}}{1\,minute}\right) = \frac{9\,beats \times 10}{minute} = \frac{90\,beats}{minute}$$

$= 90$ BPM

$$\frac{90b}{1m} = 90\ bpm$$

Example: An ampoule contains a solution of drug of 300 µg/5mL. Convert this dose into g/L

$\frac{1\,\mu g}{10^{-6} g}$ or $\frac{10^{-6} g}{1\,\mu g}$

$1\ \mu g = 10^{-6}\ g$ and $1\ ml = 10^{-3}\ l$

$1 \times 10^{-6}\ g$

$\frac{1\,mL}{10^{-3}\,L}$ or $\frac{10^{-3}\,L}{1\,mL}$

$$300\,\frac{\cancel{\mu g}}{5\,\cancel{ml}} \times \left(\frac{10^{-6}\,g}{1\,\cancel{\mu g}}\right) \times \left(\frac{1\,\cancel{ml}}{10^{-3}\,l}\right) = \frac{300\times10^{-6}}{5\times10^{-3}}\frac{g}{l} = 0.06 \approx 0.1\ g/l$$

S. Mudunde

Everyday Example

Ronnie wants to estimate how much money he will spend on gas driving back and forth from campus this term. A round-trip to campus is 14.2 miles, his car typically gets 27 miles per gallon (**MPG**) and gas is currently **$2.86** per gallon. He needs to drive to campus and back four times per week. Let's predict his cost for gas during the 11 week term.

$$11\,weeks\,per\,term = \left(\frac{11\,weeks}{1\,term}\right)\left(\frac{4\,trips}{1\,week}\right)\left(\frac{14.2\,miles}{1\,trip}\right)\left(\frac{1\,gallon}{27\,miles}\right)\left(\frac{2.86\,dollars}{1\,gallon}\right)$$

$$= \left(\frac{66.18\,dollars}{1\,term}\right) = 66.18\,Dollars\,per\,term$$

Average heart is 80 BPM

Everyday Examples: Heart Beats Per Lifetime

We start with the average lifespan, which we will round to 80 years for simplicity:

$80\,yr = 80\,yr \cdot \frac{365\,d}{1\,yr} \times \frac{24\,hr}{1\,d} \times \frac{8b}{m}$

$$80\,\mathbf{yr} = 80\,\cancel{\mathbf{yr}}\left(\frac{365\,\cancel{days}}{1\,\cancel{\mathbf{yr}}}\right)\left(\frac{24\,\cancel{\mathbf{hr}}}{1\,\cancel{days}}\right)\left(\frac{60\,\cancel{\mathbf{min}}}{1\,\cancel{\mathbf{hr}}}\right)\left(\frac{80\,beats}{1\,\cancel{\mathbf{min}}}\right) = 3,363,840,000\,beats$$

We have estimated that one lifetime will contain over three billion beats!

80 beats → 1 min
→ 80 yrs.

80 beats → 1 min
x → 80 x 365 x 24 x 60 mi

80 x 80 x 365 x 24 x 60

S. Mudunde

Exercises

You want to give 50 **mg/kg** of Fortaz to a child who weighs 25.5 **kg**. Fortaz is available in an oral suspension labeled 100 **mg/mL**. How many **mL** should be administered?

$50\ mg/kg \times 25.5\ kg \times \frac{1\ mL}{100\ mg}$

Solution

$$50\ \frac{\cancel{mg}}{\cancel{kg}} \times 25.5\ \cancel{kg} \times \frac{1\ mL}{100\ \cancel{mg}} = 12.75\ mL$$

$$\approx \underline{\underline{12.8\ mL}}$$

SCALARS AND VECTORS

- In our study of physics, we often need to work with physical quantities that may have numerical and/or directional properties.
- Scalars – physical quantity that has magnitude only. No direction associated

Ex: 5 apples, 2 books, mass, time, distance
Speed

29

- Vectors – physical quantity that has both magnitude & direction.
- A complete statement about the vector quantity you need to state the two (mag & dir)

Ex: displacement, Velocity, Current, magnetic field
force, acc., moment.

Diff. btn Speed & Vel.

- A car is moving at 50 km/hr $\rightarrow$ mag | Speed

  $\underbrace{\hspace{6cm}}_{\text{Scalar}}$

- A car is moving at 50 km/hr eastward | Velocity

  $\underbrace{\hspace{6cm}}_{\text{Vector}}$

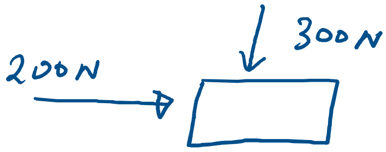
31

Addition of Scalars

- Since Scalars are simply numbers representing magnitudes, the can be added the way we add 2+3.
- 5 kg + 3 kg = 8 kg.
- 8 Seconds + 1 Second = 9 Seconds

32

- What about



- Can we just add them as
  200 + 300 = 500 N ?

- NO, force is a vector, it has both mag. & dir. Therefore they have to be added vectorially.

33

Representation of vectors.

- Consider vector A and vector B
- To denote them, we write them with an arrow on top or bold face.

vector: $\vec{A}$ or $\vec{A}$ or $\mathbf{B}$

magnitude: $|\vec{A}| = A$

$|\vec{B}| = B$

34

Example:

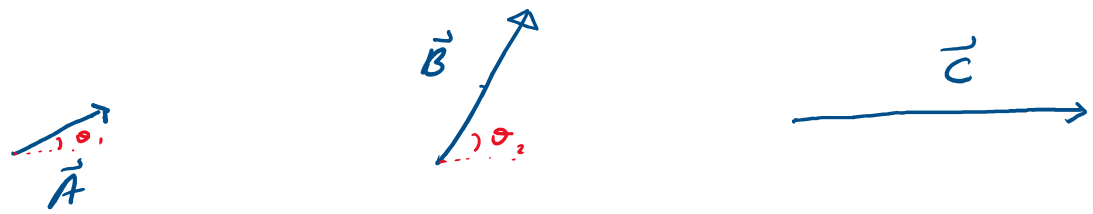
A car is travelling at 20 km/hr due east. What is the velocity and speed.

Velocity $= \vec{v} = 20\ km/hr$, east

Speed $= |\vec{v}| = 20\ km/hr$.

35

Representation of Vectors Continued

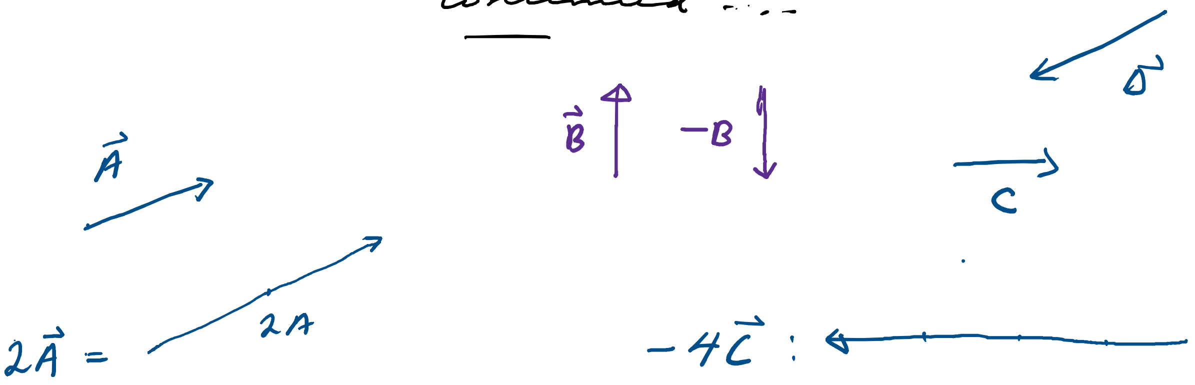


- The magnitude is the length of the arrow.
- Direction is the angle θ

36 S. Mudenda

Representation of Vectors

Continued ....



- A negative vector of A is a vector with same mag. as $\vec{A}$ but in opposite direction

Representation of a Vector

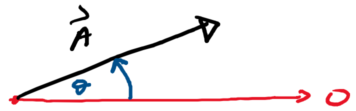
- Represented by an arrow of known length.
- The magnitude is the length of the arrow
- The direction is the is the angle theta (θ).
- But ~~how~~ how do we describe θ?

 S. Mn

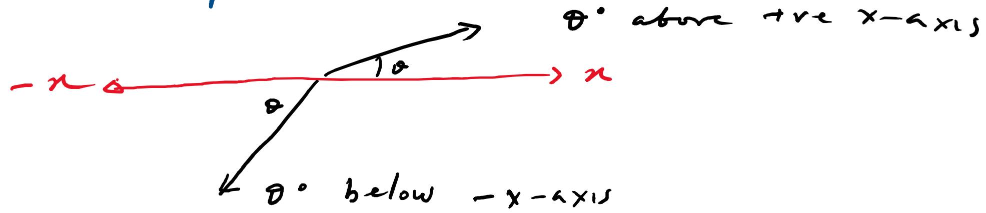
Describing direction, θ.

Direction can be described in terms of

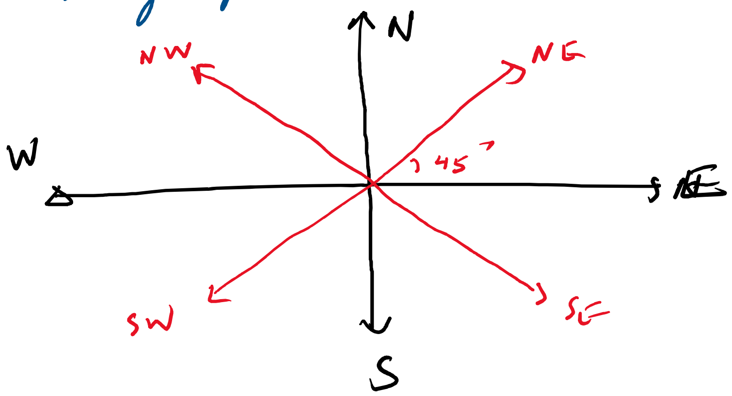
1. With respect to 0 and anti clockwise direction (acw)



2. With respect to the x-axis



3. Geographical notation



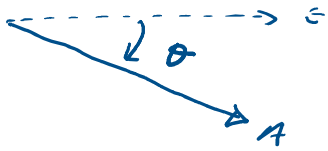
S. Mhlanga

Example:

1. A vector directed NE or SE or SW or NW are all at 45°.

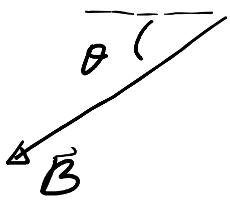
2. Vector $\vec{A}$ directed θ South of East

   is a vector with mag A, directed in the easterly direction but rotated θ° South.



θ, SE

3.



Vector with mag B and directed in the Westerly direction but rotated θ° South

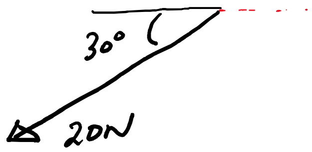
θ° South of west.

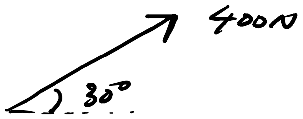
or θ° SW.

Vector notation: $\vec{B}$, θ° SW

S. Mudende

Describe the Vector in terms of 3-notations.





- 200N @ 210°.

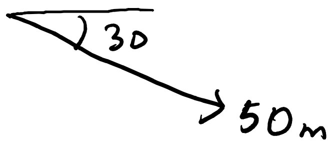
or

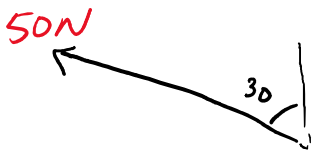
- 200N @ 30° below the negative x-axis
- 200N @ 30° South of west.

- 400N @ 30°

or

- 400N @ 30° above the +ve x-axis
- 400N @ 30° north of east.





- 50m @ 330°

or

- 50m @ 30° below the +ve x-axis

or

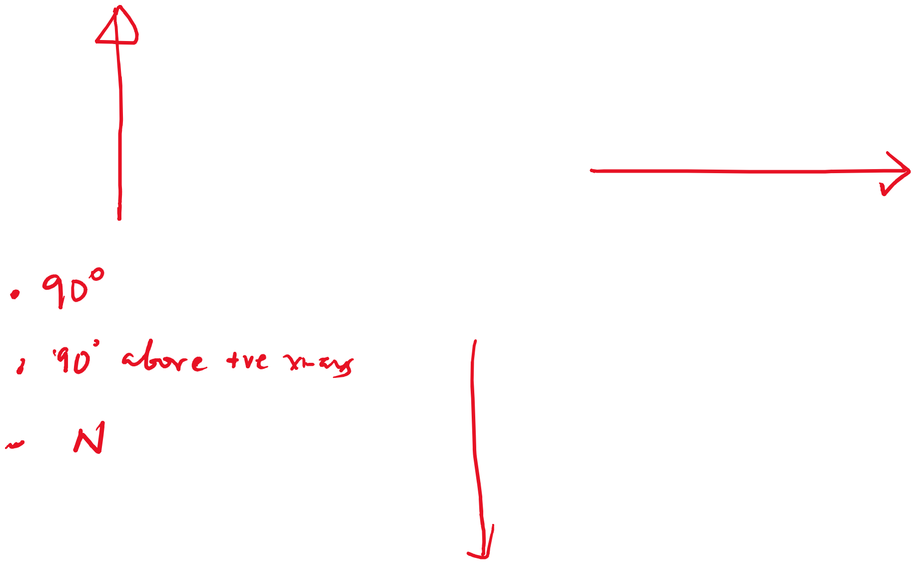
- 50m @ 30° South of east

- 50N @ 120°

or

- 50N @ 60° above the -ve x-axis
- 50N @ 30° west of north

S. Mukherjee



45

Addition and subtraction of Vectors:

Vectors can be added (subtracted) using two methods.

1. Graphical method
2. Rectangular / analytical method

46

S. [illegible]

Graphical method

You need:

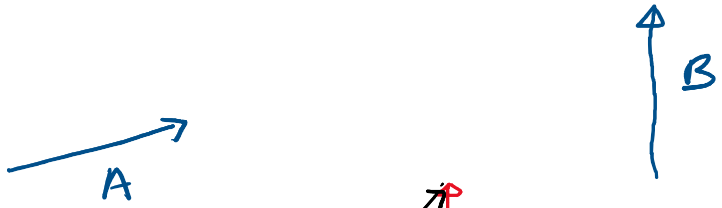
1. pencil / pen
2. protractor (for direction)
3. ruler (magnitude)
4. paper.

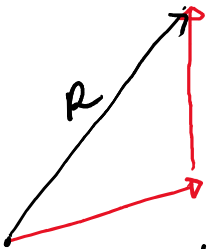
- To add or subtract vectors, you first draw vector $\vec{A}$ on a paper, with its magnitude represented by a convinient Length scale, and then draw vector $\vec{B}$ to the same scale with its tail starting from the tip of A.

$\vec{A} + \vec{B}$

S. Mudede

- Connect the head of the first to the tail of the second vector.





$\vec{R} = \vec{A} + \vec{B}$

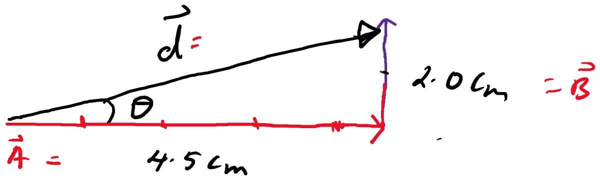
- The resultant vector ($R = A + B$) is a vector drawn from the tail of the 1st vector to the tip of the ~~second~~ last vector

49

A bus travelled for 45 km eastward and 20 km north. What is the displacement?

Scale:

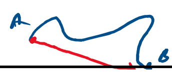
10 km $\rightarrow$ 1 cm
45 km $\rightarrow$ 4.5 cm
20 km $\rightarrow$ 2.0 cm



$\vec{d} = \vec{A} + \vec{B}$

$\simeq 5\,m$ @ $24°$

displacement is a vector that joins the start & end point



50

(II) Three vectors are shown in Fig. 3–35. Their magnitudes are given in arbitrary units. Determine the sum of the three vectors. Give the resultant in terms of (*a*) components, (*b*) magnitude and angle with the $+x$ axis.

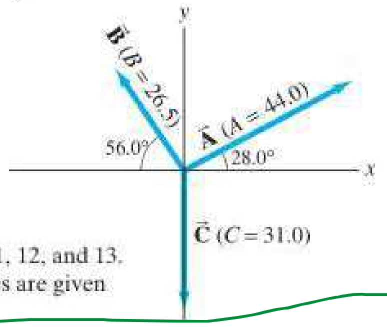
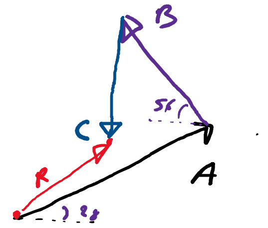


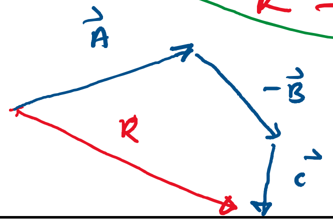
FIGURE 3–35
Problems 9, 10, 11, 12, and 13. Vector magnitudes are given in arbitrary units.



$\vec{R} = \vec{A} + \vec{B} + \vec{C}$

What about $\vec{A} - \vec{B} + \vec{C}$

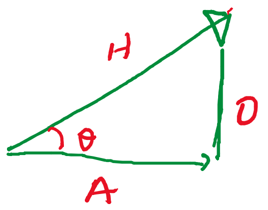
$\vec{R} = \vec{A} + (-\vec{B}) + \vec{C}$



Analytical method of adding/subtracting Vectors.

What you need:

- paper, pen, calculator
- knowledge of trigonometry.



SOH CAH TOA

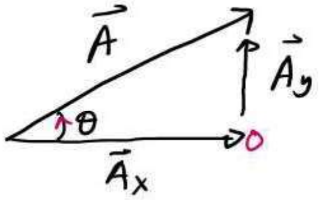
$\sin\theta = O/H$: $O = H \sin\theta$

$\cos\theta = A/H$: $A = H\cos\theta$

$\tan\theta = O/A$: $\theta = \tan^{-1}\left(\frac{O}{A}\right)$

S. Mudiadu

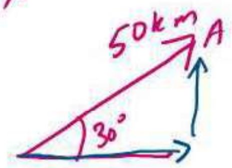
Any vector can be resolved into its constituent components.



$$\vec{A} = \vec{A_x} + \vec{A_y}$$

$$A_x = A \cos\theta$$
$$A_y = A \sin\theta$$

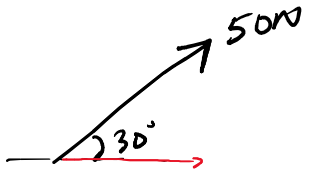
Ex



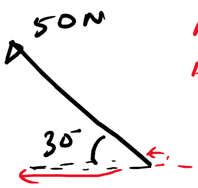
$A_x = 50 \cos 30 = 43.3\,\text{km}$

$A_y = 50 \sin 30 = 25.0\,\text{km}$

Example: Calculate the x & y components of the following vectors



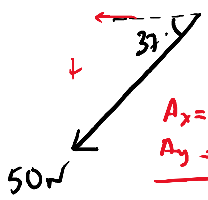
$A_y = 50 \cos 30$
$A_y = 50 \sin 30$



$A_x = 50 \cos 150°$
$A_y = 50 \sin 150$

or

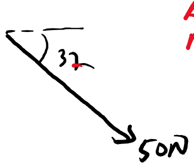
$A_x = -50 \cos 30$
$A_y = 50 \sin 30$



$A_x = 50 \cos 217$
$A_y = 50 \sin 217$

or

$A_x = -50 \cos 37$
$A_y = -50 \sin 37$



$A_x = 50 \cos 323$
$A_y = 50 \sin 323$

or

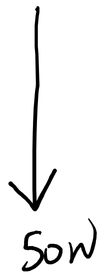
$A_x = 50 \cos 37$
$A_y = -50 \sin 37$

$A_x = 0$
$A_y = 50$

or

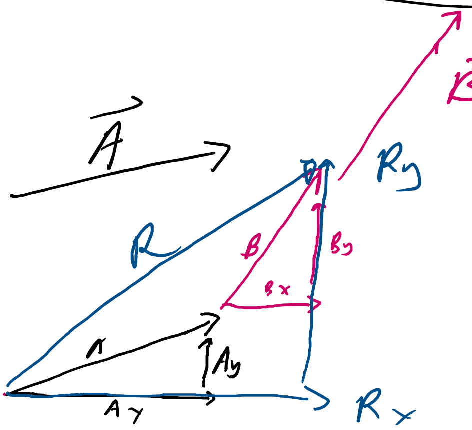
$A_x = 50 \cos 90 = 0$
$A_y = 50 \sin 90 = 50$

$A_x = 50, \quad A_y = 0$



$A_x = 0, \quad A_y = -50N$

Adding & Subtraction of Vectors



$\vec{R} = \vec{A} + \vec{B}$

$R_x, \; R_y$

In general for multiple vectors,

$R = A + B + C + D$

$R_x = A_x + B_x + C_x + D_x$

$R_y = A_y + B_y + C_y + D_y$

$R_x = A_x + B_x, \quad R_y = A_y + B_y$

S. [illegible]

$\Rightarrow$ Next: Analytical addition of vectors.